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INFORMATION PROCESSING IN THE FUNCTIONAL VISUAL FIELD

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INFORMATION PROCESSING IN THE FUNCTIONAL VISUAL FIELD

A. F. Sanders

abstract

1. Introduction /1*

A preliminary theory was published a few years ago covering the functional organization of the visual field. This theory was based on experiments relating information assimilation to the visual angle at which signals are presented (Sanders 1963). It is now clear that this theory must be modified and expanded before it can serve as an adequate first approximation of a functional theory of the visual field. The changes presented below suggest that the experiments described (Sanders 1963) should be reexamined on a broader basis. For convenience the previous experiments and the conclusions drawn from them are summarized first. The revised theory is given in Section 3. The last section describes the impact of the results on the general theory of the functional visual field.

2. Summary of the Study

The main point of the paper (Sanders 1963) is that the efficiency of information processing as a function of the visual angle of signals presented declines in stepwise fashion. This is illustrated in Fig. 1, where average performance in a continuous visual reaction task is plotted as a function of the visual angle. In addition to a gradual decline of the performance, a sudden drop occurs at two visual angles. In this experiment two signals were shown simultaneously on a screen. They consisted of a vertical column of dots (four or five under one condition and two or three under another), just above eye-level and at the same distance from the meridian plane of the subject. There was a different reaction key for each possible pair of signals, and the proper key was to be depressed as soon as possible after a pair was displayed. After a reaction a new pair followed automatically so that a continuous reaction task was created. Performance was equivalent to the number of reactions in five minutes. An analogous task was used previously in a study of the relation between noise effects on work performance and the angular range in the visual field over which signals were presented /2
(Sanders 1961). In the display the left signal (S_1) was fixed and the subject was free to shift fixation to the right signal (S_r) by moving his eyes and head. In Fig. 1 the transformed performance scores are plotted for both conditions (2 and 3 or 4 and 5 points).

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* Numbers in the margin indicate pagination in the foreign text.

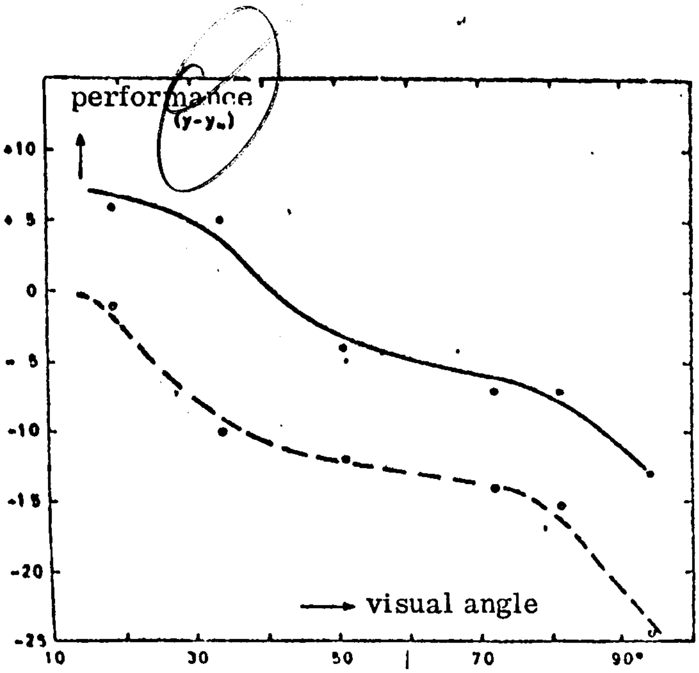

Figure 1. Performance in a Continuous Reaction Task as a Function of the Visual Angle at Which Two Signals are Presented Simultaneously. The Solid Line Represents Reactions to Groups of Points of Four or Five Elements. The Broken Line Refers to Groups of Points Consisting of Two or Three Elements.

The essential reason for the decline in performance was studied in all sorts of variations of the above-described experiment. In one study the reaction times (RT) were measured for single flashings of pairs of signals consisting of four or five points. In this study the subject was instructed to perform the task exclusively through peripheral vision or by moving his eyes. The results showed a correlation between the areas where the decline in performance was found and those where peripheral vision and eye motions, respectively, were insufficient to guarantee an optimal RT (see Fig. 2). /3

In other studies eye and head movements were measured simultaneously with the reaction task. These confirmed the last conclusion. It appears then that there are three functionally important areas in the visual field. These are the following: the stationary field, the eye field, and the head field. They can be distinguished on the basis of the efficiency of the processing strategy and by the necessity of using extra mechanisms for the shifting of attention. The angular range of these fields depends on the complexity of the signals and, as appeared from further studies, on the extent to which perception is burdened in general. /4

The simultaneous measuring of eye and head movements demonstrated further that the decline in performance was not a result of the introduction of these movements. The time necessary to move from S_1 to S_r appeared to be linear over the whole area measured, with the exception of a deviation in the stationary field, the range of which encompassed only a fraction of the decline in performance. The decline appeared to be linked specifically to the elapsed time between the instant the eye apprehended S_r and the final reaction. The fixation time of S_1 is almost constant.

This led to the hypothesis that in the stationary field and the eye field the subject definitely expects to see S_r while he is still fixing S_1. The essential function of the fixation shift of the eye is thus to verify an assumption. In the head field, however, a new discrimination is needed that requires much more

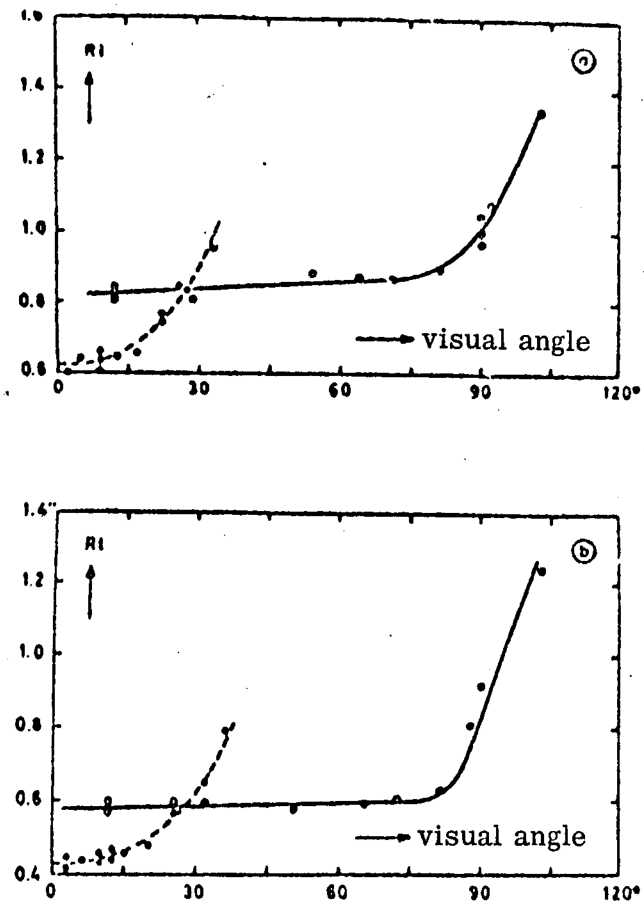

Figure 2. The Reaction Time as a Function of the Visual Angle at Which Two Signals are Displayed Simultaneously. The Broken Line Represents the Result When the Subject was Instructed to Fix S_1 Continuously. The Solid Line Shows the Result When Eye Movements were Allowed. a and b are Data for Different Subjects.

time. These hypotheses were tested in an experiment where S_r disappeared during the fixation of S_1 or the movement of the eye. Subjects then were able to name S_r almost without error and with a very high degree of confidence, when the signals were inside the stationary field. Also in the eye field the naming of S_r was much better than chance, but the confidence was much less. As soon as we go from the eye field to the head field, however, correct identification is practically a matter of chance. This then provided strong support for the above-mentioned assumptions, but these of themselves do not yet offer an explanation of the decline in performance.

Though it has repeatedly been found that the RT is shorter for an expected signal than for an unexpected one, it still is not quite clear why the fixation time of S_1 does not increase if, in addition to discriminating S_1, the subject is also "working on" S_r. If the latter were the case, this would negate the advantage of the reduced S_r fixation time. In the paper this question was related to the concept of perceptive random sample, i.e., "the view that no stimulus can act instantaneously but rather that there is a continuous sequence of changes at the sense organs and that each decision is taken on the basis of a sample of these changes over a finite period of time" (Broadbent, 1958; p. 278). Provided both signals occur within the same random sample, they are thus perceived (grouped) as one signal by the decision-making mechanism. This one signal, however, contains more information, namely two bits, than when the signals are distinguished successively. /5 The solution to this problem was provided by the relatively small increase of RT as a function of the information content, as reported from a great variety of experiments. Thus a complete grouping process was finally assumed in the stationary field, and in the eye field as well, although with the reservation that correct identification of S_r is uncertain, so that verification is necessary. Lastly, in the head field two independent observations would have to be made.

3. Theoretical Reevaluation

Thus it is clear that the linking of perceptive random sample, information content, and RT gives no adequate explanation for the decline in performance. If RT is plotted as a function of the information content, the relation is always linear, but the direction factor varies strongly and appears to depend on what Fitts has called the "signal response compatibility" (Fitts and Seeger, 1953; Broadbent; 1963).

When the reaction flows "naturally" from the signal by reason of configuration or prolonged training, there is practically no increase in RT (Fitts and Biederman, 1965; Mowbray and Rhoades, 1960), but if the compatibility of signal and response is not so good, the direction factor increases (Simon and Wolff, 1961; Broadbent, 1963). The theoretical meaning of the S-R compatibility for the reaction process is considered elsewhere more extensively (Sanders, 1967a). Here it suffices to state that the RT for one signal containing two bits is not necessarily smaller than the sum of the RT's for two signals each containing one bit. This depends on factors which are not primarily perceptive, as for instance S-R compatibility. In addition, the latter was not very great under the conditions of the visual field experiments. Thus one of the cornerstones of the theory disappears. Also the idea of the perceptive random sample, as defined previously, hardly seems to apply. But there is evidence for the existence of a psychological moment with an established periodicity. A period of about 100 msec is regularly reported in the literature (Stroud, 1955; Latour, 1966; White, 1967). Also it is not unlikely that this period is related to some forms of perceptive integration, as the experiments on "numerosity" observation suggest (White, 1967). On the other hand it is not impossible that the psychological mo- /6
ment is determining for the assumed possibility that different data are conceived as one signal. For the theory of the functional visual field this means that a new basis must be found to explain why the S_1 fixation time is not influenced by the extent to which information is obtained about S_r (see p. 3).

A first suggestion on where to look is found in Macworth's recent discussion of the "useful field of view," which is defined as "the area around the fixation point from which information is being briefly stored and read out during a visual task" (Mackworth, 1965). This field, which shows similarities with the eye field, "cannot exceed the normal physiological limits set by the ordinary visual acuity fields .... overload from too many unwanted signals can prevent the useful field from reaching the size of the normal plotted fields." Exactly the same can be applied to the eye field.

Macworth links the "useful field" to the "visual image," an immediate memory in which the signals would be stored uncoded (Sperling, 1960). The data are ultimately read out of or decoded from the visual image successively (Mackworth, 1963; Sanders, 1964a); a central "scanning process" is implied. The reading of the visual image can be taken quite literally because Mackworth

(1963) demonstrated that with a short presentation time the number of reproduced units is related to the reading speed of the type of data.

It is not impossible that in scanning the visual image a succession of codings takes precedence over carrying out a complete reaction after each coding. It is safe to assume this if the data in the visual image lead to recoding, i.e., that a learned rule is used to bring a certain group of signals under one denominator. When recoding rules can be used in a visual task the efficiency of the processing method is considerably greater than a successive reaction to each signal. Further analysis of the concept of grouping points in the same direction. Broadbent used the idea of the perceptive random sample mainly to explain grouping phenomena in the so-called psychological refractory period (PRP). In the experiments on the PRP the RT's are determined for two signals that follow each other /7
rapidly. Under some circumstances the signals are considered strictly successively (see Bertelson, 1966; and Sanders, 1967b for recent references) according to the formula

$$RT_2 = 2\ RT_1 - I\ (I \leq RT_1)$$

where RT_1 and RT_2 represent the reaction times to S_1 and S_2, and I designates the interval between S_1 and S_2. This type of result is encountered in the functional visual field mainly when the signals are located in the head field. This was demonstrated experimentally when separate reactions were given to columns of points presented at the same time. When the subject was instructed to apply the strategy of successive processing in the stationary field and the eye field, the RT no longer was different from that in the head field. It was also difficult to carry out the instruction, as we see from the fact that in 50% of the cases measured the eye had already shifted to S_r before the reaction to S_1 was concluded. In the head field, however, the instruction was carried out easily. The subjects can also be told to group; this means that both signals must be precieved before a reaction is carried out. The formula for this is as follows:

$$RT_1 = RT_2 + I - c\ (I < RT_1)$$

where c is the time needed to complete RT_2 motorically after RT_1. Grouping was the most efficient strategy in the stationary field and in the eye field. It is then in effect easier in these fields to read all perceptive data before carrying out a reaction. This is not necessarily to be expected in the head field because the limits of the eye field would also be those of the visual image. In the PRP, grouping is found particularly at small intervals, and then practically only when choice reactions are asked. This last limitation makes the theory of the perceptive random sample untenable, because then the grouping would have to be independent from the kind of signals.

The relation between the efficiency of grouping and the use of rules for recoding remained in the background in the PRP studies despite the fact that it is explicitly suggested in the classical article of Craik (1948): "It seems that groups of stimuli, composing letters of morse for instance, must have been learned previously and that these groups then become single stimuli with which the computing system deals as wholes." [sic] Bertelson (1966) recently returned to the subject and added that it is of paramount importance for the theory of data processing to know the range of the units on the basis of which the subject decides to give one answer or a series of answers. /8

Thus conceived, grouping is linked to the classical controversy over the essence of the stimulus: Is this one single signal where a "percept" consists of a collection of elements, or did the percept itself become one signal? The dispute between the advocates of the atomistic view and those of the Gestalt viewpoint comes up again here; the discussion has been repeated in many forms since. Hebb's phase sequences (Hebb, 1949), Lashley's publication on serial order in behavior (Lashley, 1951) and the perceptive "chunk" (Miller, 1956) are just some modern examples. The difference with the Gestalt theory, moreover, lies in the fact that it is not so much perceptive units or elements which are involved but decision units. A decision unit is not only determined by the perceptive characteristics of the stimuli but also by learned or innate rules that can bring a certain group of stimuli under one denominator. Miller demonstrated that subjects who can work with the binary system of numbers have an immediate memory capacity for sequences of the numbers 0 and 1; this is characteristic for the grouping or recoding of a series of elements into one decision unit. With a highly perfected skill such as reading one can imagine that such decision units are perceived and reproduced very rapidly. In any event there will be an almost natural tendency to read a whole series of elements instead of considering them one by one as is suggested in formula 1 in the context of PRP. This can only be expected when sequences of signals occur that are simple or have little mutual structuring. The PRP studies used mostly simple a-reactions with irregular intervals between S_1 and S_2, and under those circumstances a strong domination of (1) is found.

4. Consequences for the Theory of the Functional Visual Field

The main consequence of the view on grouping just described is that the different fields in the functional visual field are related in a very specific way to the possibility of organizing perceptive material. In the stationary field and in the eye field it should be possible to form recoded decision units, "chunks", or Gestalten. This possibility is lacking in the head field. In the eye field the decision unit is subject to the provision that only an assumption concerning S_r is possible. The subjective probability attached to this hypothesis depends, of course, on the peripheral sharpness of vision. Such decision units are plainly apparent with verbal material and are slightly less clear with visual configurations. The law of the good shape has always been a subjective matter. In the case of two columns of points it can be imagined, for example, a decision is taken on the basis of equality or inequality of the relative length. /9

However this may be, today's theory implies that the efficiency of the grouping process depends on the perceptive structure of the material. This means that the drop in performance accompanying transitions between the different fields is also connected with the perceptive structure. If "chunking" is impossible, it must be expected that RT increases exclusively as a result of the longer duration of the fixation jump. This line of thought is supported by a recent experiment in which two signals (S_l and S_r) were presented at an interval of 0.1 sec. S_l originated from the left groups of Fig. 3, and S_r from the right ones. In this experiment the organization of the signals shown under A and B were used among others. Under condition A the total time to react to two signal groups was significantly less than the sum of RT_l and RT_r when the signals were presented independently. Under condition B this difference had disappeared (Sanders, 1967c).

X 0 0 X
X 0 0 X   0 0 0 0 0 0
X 0 0 X   X X X X X X

Figure 3. Signal-Response Configurations and Differences in Perceptive Organization.

The preceding ideas must now be further elaborated within the framework of the theory on the functional field of vision. This applies especially to the conclusion that Gestalt formation in the head field does not develop independently. There are all sorts of impressions in the literature concerning shapes "good" in themselves which cannot be directly recognized as such, if the enlargement is too great. When is the image too big? There may be a connection with the complexity of the shape. But the head field also varies considerably with the complexity of the perceptive structure of the task. In the /10 1963 paper (Sanders 1963) there is one explicit example where it appeared that perceptive organization in the head field was no longer apprehended. When a series of plus and minus signs was imprinted, redundancy in the eye field led to improved reproduction. The redundancy consisted of the fact that the second half of the row was an absolute repetition of the first. In the head field there was no longer a difference between redundant and non-redundant rows. The original conclusions that two perceptive random samples are needed to comprehend the material in the head field can possibly be explained by saying that at least two decision units are involved, so that recoding on the basis of the identity of the halves does not occur in simple fashion.

On the basis of this discussion it is likely that transition from one field to the other in perceptive performance occurs mainly when the signals are limited in number, all contain little information, and together they form a definite structure or number of structures. When there is a large number of signals and each signal contains a surplus of details, much of the specific assumption activity the eye field will be lost. All tests in the 1963 paper met the last-mentioned conditions. We can also point out transitions between fields in the results of other research workers. Thus Adams et al. (1963) found a relatively large increase in the average RT in an observation task if the service panel exceeded a certain visual angle. Morrow and Salik (1962) reported a sharp decline in the efficiency with which data in the outside mirrors of cars are evaluated if the visual angle with respect to the position of the driver exceeds 45°. Baker (1967) examined the speed at which radar signals are detected and compared a moving and a stationary search line in his study. The visual angle lies within the stationary field when the line is stationary, according to Baker, while the angle would fall in the eye field if the search line were moving. In any event the stationary search line gave a much better performance.

The data of Mackworth (1965) pointed to different results. These data concern detection of minor details on complex photographs and distinction of letters in a page of text. In such cases a tedious searching process takes place within the eye field without the slightest indication of grouping or hypothesizing. But /11
grosser structures, such as open spaces, the edges of pages and objects from the environment are seen. Details are likely to be simply ignored when too many signals are presented and the subject will probably limit himself to a number of super chunks. The details in a page of text are reproduced poorly in the visual image. This is the result, among other things, of mutual inhibition of peripherally presented signals (e.g., Woodworth and Schlosberg, 1954). If the task consists in finding such details, it can safely be assumed that no use is made of the recoding principles that are available in the eye field.

In conclusion it can be said that the examples described in the paper throw light only on the macrostructure of the functional visual field. The different fields are mainly of importance in connection with this macrostructure. The main benefits of the current discussion are evidently the recognition of the limited range of applicability and the better understanding of the relation between the fields and perceptive organization. We then have scarcely more than a basic foundation for a theory of the functional visual field. But the experimental possibilities are legion.

Summary /12

It has been found that performance in a number of visual tasks does not linearily decline as a function of visual angle. Instead, there are stepwise drops at two visual angles, which proved to be the boundaries of the areas where inspection by means of peripheral vision and eye movements were sufficient to obtain optimal performance. The drops were explained in terms of strategies in processing visual information, which were thought to vary from grouping signals at small visual angles to successive handling at very large angles. This theory is reevaluated in the light of more recent notions on visual coding and recoding. Especially the relation between grouping and perceptual organization is considered. It is concluded that the earlier work is restricted to the macrostructure of the functional visual field.

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